A LATE-SEASON STORM OVER THE PLATEAU AREA

James F. O'Connor and Lewis C. Norton

WBAN Analysis Center, U. S. Weather Bureau

Washington, D. C.

On June 6, 1950, a storm developed over Nevada along the leading edge of a cold Pacific air mass which had moved inland across the Northwestern States. This storm resulted in the lowest pressure on record for June at some points in Nevada and northern Utah; the lowest pressure (reduced to sea level) was about 984 mb. just west of Wendover, Utah, at 0030 GMT on June 7. In its later history (June 7–10) the storm followed an unusual path, making a loop in the Northern Plains as it migrated from Nevada to Ontario, as shown in Chart III following page 111.

The storm brought unseasonably low temperatures as far south in the Great Basin as northern Arizona and northern New Mexico. Frost was widespread in these areas on the mornings of the 7th and 8th, damaging truck crops in portions of Utah, Arizona, Nevada, and California [1]. Reported minima included 28° F. at Blue Canyon, Calif., on the 6th and 7th, 33° F. at Milford, Utah, on the 5th and 6th, and 34° F. at Elko, Nev., on the 7th. The passage of this storm eastward also brought abnormally low temperatures in the northern Great Plains, including near freezing temperatures and light frosts in North Dakota. Glasgow, Mont., had a minimum of 32° F. on the 8th.

Heavy precipitation accompanied the storm in some sections of the northwestern and north central United States. General rains in the Northwest were beneficial to unirrigated crops. Pendleton, Oreg., had rain on the 6th, 7th, and 8th, ending a drought which started in early May. Snow fell at higher elevations in Washington, Oregon, Idaho, and northern California; Blue Canyon, Calif., reporting a total of 4.3 in. Light snow occurred over the Plateau as far south as Ely, Nev., and Milford, Utah. Unusually heavy precipitation fell in east and north central Montana, where Glasgow received 2.78 in. on the 7th and 8th, including a trace of snow. Widespread wet snows occurred over western Montana on the 7th and 8th with Great Falls reporting a total snow fall of 11.1 in. Subsequent rains cleared away the snow by the morning of the 9th.

In many areas of the west and central Great Plains, however, lack of rain combined with high winds was damaging to crops. Drought conditions were not alleviated in southeastern Colorado, and high winds and dust storms were general over that State, causing damage to power lines, trees, and buildings in the west central and southwestern portions. Dust storms also occurred in Arizona and Nevada. Strong winds and dust on the 6th and early on the 7th aggravated drought conditions in south central Idaho. Trees and crops in southern California were damaged by strong winds on the 6th and 7th.

CONDITIONS PRECEDING FORMATION OF THE NEVADA LOW

On the morning of June 5 there was a weak disappearing surface Low just west of Cape St. James, B. C., which, during the preceding 24 hours, had moved eastward about 450 miles and filled about 12 millibars. At the same time the associated cold front had moved into eastern Washington and Oregon.

At the 500-mb. pressure surface at 0300 GMT of the 5th (fig. 1) the Low was centered directly over this surface Low, having moved eastward and filled by about 200 feet in 24 hours. Unlike the surface Low, it was still an intense system because of very low upper air temperatures. The isotherm of −25° C. surrounded the center at 500 mb. and the temperature at the center was about −30° C. The surface Low had filled mostly because of an influx of

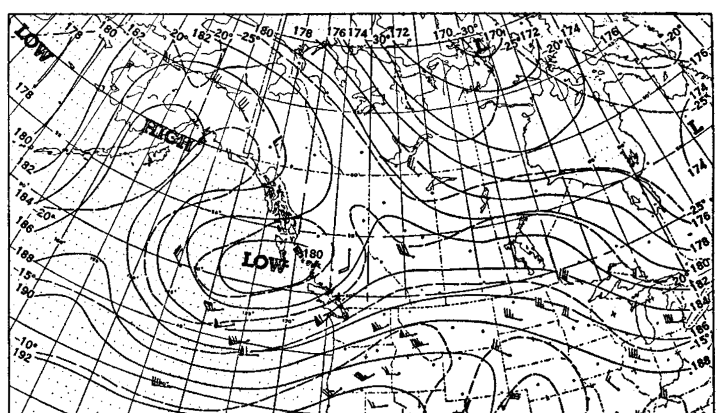

Figure 1.—500-mb. chart for 0300 GMT, June 5, 1950. Contours (solid lines) at 200-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) are drawn for intervals of 5° C. Barbs on wind shafts are for wind speeds in knots; full barb for every 10 knots, half barb for every 5 knots, and pennant for every 50 knots.

colder air over the center at low levels while the filling of the upper Low resulted chiefly from stratospheric cooling.

At the same time (fig. 1) an east-west ridge extended from Whitehorse, Y. T., westward to near Anchorage, Alaska, and fairly strong northwest winds were approaching a region of markedly anticyclonic contour curvature around Yakutat, Alaska, and Whitehorse. Since the contour pattern was changing slowly relative to the speed of the approaching northwest winds, the higher speed air parcels cut across the contours toward lower height as they passed through the region of sharp contour curvature. This process caused a further increase of speed and some anticyclonic curvature in the trajectories, but less curvature than that of the contours. The resulting southward and then southwestward trajectories, carrying air across the contours, explained in part the rising contour heights in the northern portion of the Low, and the resulting southward movement seen on subsequent charts.

On the west side of the Low there was a narrow north-south ridge. As some of the fairly strong southwesterlies west of the ridge approached the diverging contours near 50° N. 155° W., they overshot anticyclonically into the cyclonically curved western portion of the Low. This effect, combined with that mentioned in the previous paragraph, suggested considerable filling in the west end of the Low. Eventually, accelerating air parcels from the north and west penetrated high pressure on the south side of the Low. Successive air parcels following a similar trajectory tended not only to move the Low southward but also to cause the westward-extending trough to swing rapidly around to the southern side of the Low.

At the 500-mb. surface at this time (fig. 1) the anticyclonic circulation centered at Reno, Nev., was also of interest because of its subsequent effect on the dryness of the southwestern United States as it moved eastward.

By 0300 GMT, June 6 (fig. 2) the 500-mb. Low had moved to a position near Tatoosh Island, Wash., and a trough extended southward to near 40° N. and 130° W. Northerly winds of 70 knots were evident southwest of the Low. This high speed air was in a position to move cyclonically into higher pressure in the south end of the trough and to eventually reach the very weak gradient along the California coast, where it caused marked divergence in that area [2]. At the same time northerly winds along the British Columbia coast indicated continued transport of cold stratospheric air southward in such a way as to contribute toward filling in the northern quadrants of the Low. Under the influence of such conditions the Low continued southward along the coast.

By 0630 GMT on the 6th (fig. 3) a weak surface Low appeared over Saskatchewan, followed by an intensifying continental Polar High. Surface pressure rises of 3 and 4 mb. over Alberta reflected at least in part the advection of continental Polar air southward. The lack of any appreciable low level warm advection east of this surface Low, and absence of indications of divergence in the upper air made it unlikely that the surface Low would develop; actually it moved eastward rapidly and filled.

FORMATION OF THE NEVADA LOW

By 1530 GMT, June 6 (fig. 4) a surface Low of 996 mb. central pressure had formed near Winnemucca, Nev., while at 500 mb. (fig. 5) the Low had moved southward to northwestern Oregon. Snow had begun to fall at Meacham, Oreg. (elevation about 4,000 feet), where the surface temperature had fallen 19° F. in 24 hours to a reading of 33°. Temperatures in the San Joaquin Valley, Calif., had fallen about 10° in the same period. By 0300 GMT, June 7 the Low at 500 mb. had reached Lakeview, Oreg.,

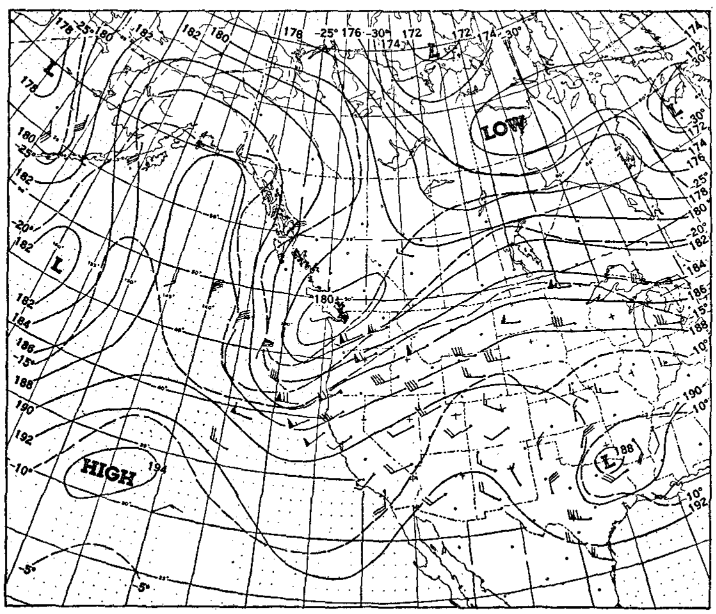

FIGURE 2.—500-mb. chart for 0300 GMT, June 6, 1950.

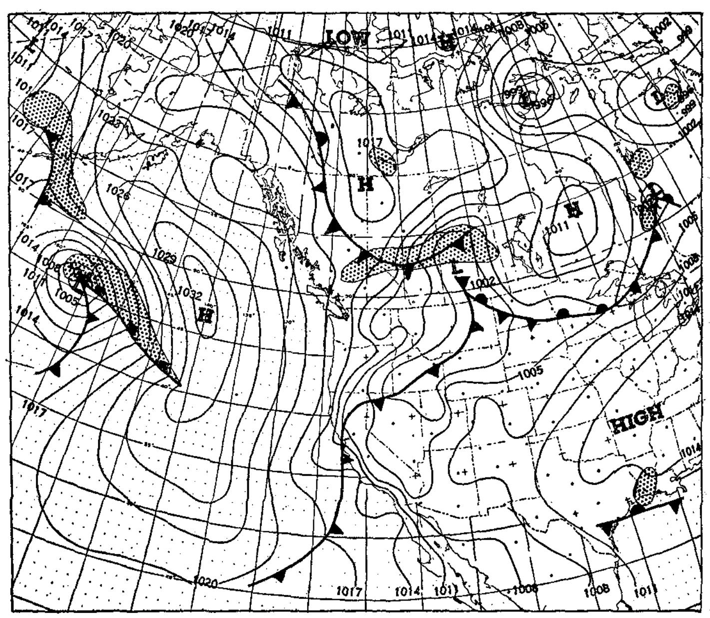

FIGURE 3.—Surface weather map for 0630 GMT, June 6, 1950. Shading indicates areas of active precipitation.

and a trough extended southward through California. Some changes in contour pattern were evident at this level; the strongest contour gradient appeared south and southwest of the Low, with weaker gradients to the east. Also the high pressure ridge off the coast appeared to be splitting west of Washington.

The surface High at 0330 GMT, June 7 (fig. 6) over Alberta had continued to intensify. A comparison of its vertical structure with that 24 hours previously (when over the District of Mackenzie), revealed that, although the troposphere over the moving center had warmed, the High had moved under a portion of the stratosphere that was higher and colder. A similar case has been described by Vederman and Norton [3]. Furthermore the local change of height of the tropopause over this area was positive. Thus the surface High was tending to become associated with high level anticyclonic conditions.

At 0030 GMT, June 7 (not shown in figures) the Nevada storm had deepened to its lowest pressure, 984 mb., just west of Wendover, Utah. By 0330 GMT (fig. 6) it had filled to about 987 mb. west of Salt Lake City. An interesting example of the intensity of the cold front, which extended southward to Arizona, is the fact that the surface temperature of the 0300 GMT radiosonde observation at Ely, Nev., was 66° F. while in the 0330 GMT synoptic report the surface temperature was 50° F. Similarly, at Las Vegas, Nev., temperature dropped from 88° F. to 73° F. between the same two observations. Strong winds were general throughout the southwest at that time with widespread dust storms occurring along and behind the front in the deep cool unstable Pacific air mass.

What were the contributing factors that caused this record low pressure over Nevada and Utah? In studying the factors which contributed to the development of record low pressure over Nevada and Utah it is of interest to determine what strata of the air above the Low contributed to the surface pressure fall. A comparison of the Ely, Nev. sounding for 0300 GMT, June 7 (fig. 7) with the sounding 24 hours previous, revealed that there had been cooling below 500 mb. which would tend to raise the surface pressure about 10 mb. The 200-mb. pressure surface, however, fell about 700 feet with considerable stratospheric warming tending to reduce the surface pressure about 25 mb. This gave a net surface pressure fall of about 15 mb. from 0300 GMT, June 6 to 0300 GMT on

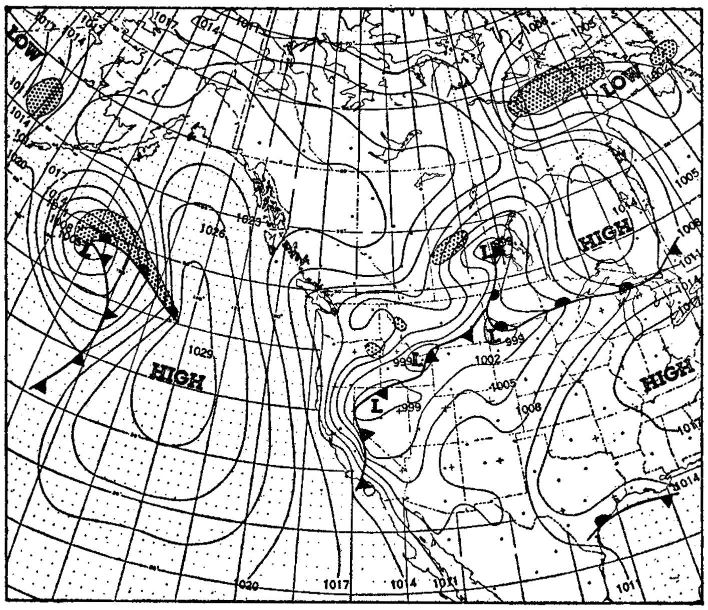

FIGURE 4.—Surface weather map for 1530 GMT, June 6, 1950. Shading indicates areas of active precipitation.

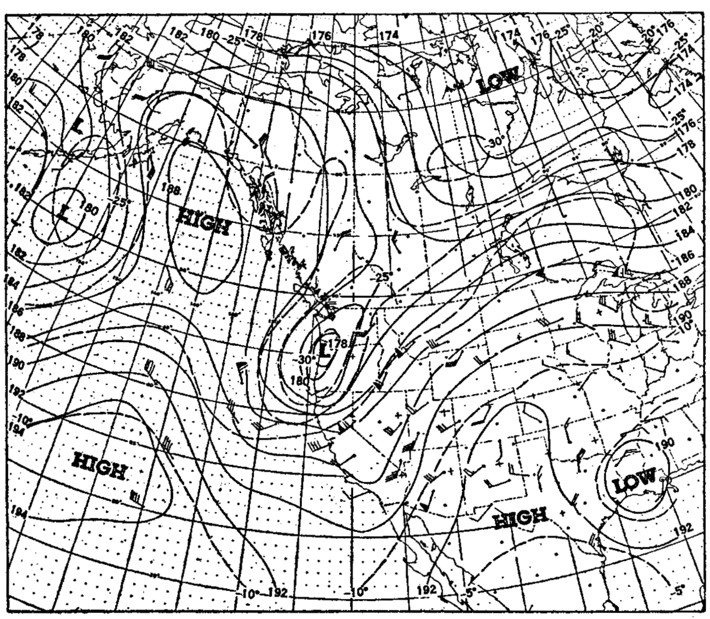

FIGURE 5.—500-mb. chart for 1530 GMT, June 6, 1950.

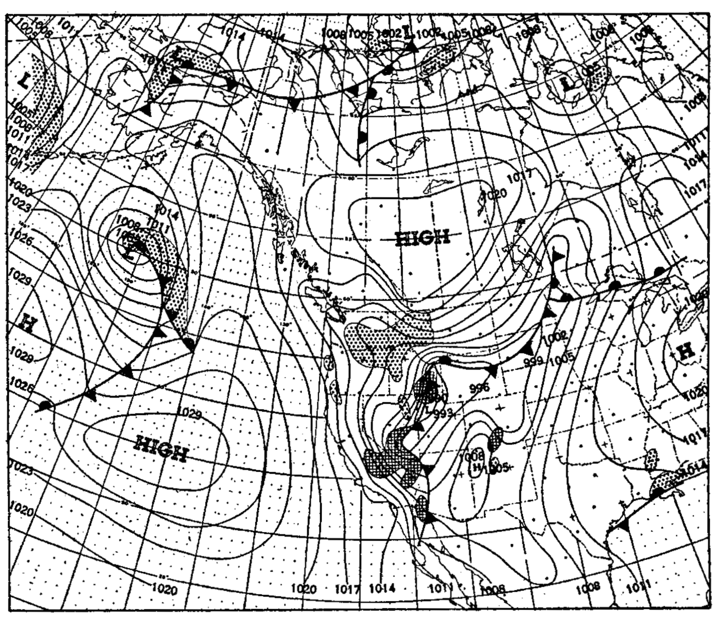

FIGURE 6.—Surface weather map for 0330 GMT, June 7, 1950. Shading indicates areas of active precipitation. Cross-hatching indicates areas of blowing dust.

89733 6—50—2

the 7th. This surface pressure fall is about 60 percent of the fall in height of the 200-mb. pressure surface. This is similar to results of studies by Vederman [4], although he compared the changes in density of the column of air in the center of a moving storm, and not the local change.

Any explanations of the fall in surface pressure must therefore involve the cause of the 700-foot decrease in height of the 200-mb. surface, and the associated stratospheric warming. As mentioned in the discussion of the 500-mb. chart for 0300 GMT, June 6 (fig. 2), parcels of high speed air moving toward the trough off the coast encountered weak gradients over the southwest, and caused marked divergence over California, Nevada, and eventually Utah. This divergence possibly caused the lowering of the stratosphere, and some of the high-level warming. The cooling below 500 mb. was at least in part the result of upward vertical motion associated with divergence at higher levels. The reason for formation of the surface Low in eastern Nevada instead of farther west, for example in California were divergence aloft was as great, is found in the compensating effect at lower levels of the more rapid tropospheric advection of cold Pacific air west of the mountains, intensified, perhaps, by vertical motion.

MOVEMENT OF STORM INTO THE PLAINS

By 0300 GMT, June 7 (fig. 8), the gradient south of the 500-mb. Low had strengthened so that air parcels from the west and northwest had little further effect in deepening the trough over California. However, upon reaching the weaker gradient in Utah, Colorado, and northeastward, deflection toward high pressure occurred, causing further divergence in that area and strengthening of the gradient over the adjacent Plains States. The deflected parcels eventually recurved northward toward lower pressure and accelerated until the Coriolis force was sufficient to cause recurvature toward the eastward. These air parcels together with those of weak winds from Alberta, both moving into the stronger gradient over Manitoba, later resulted in convergence in the cyclonic area over Saskatchewan and Manitoba and consequent lifting of the tropopause and further building of the surface High.

A similar effect was also taking place along the west coast (fig. 8). Weaker gradients to the northwest of the Low were introducing slower air into the region of strong gradient west and southwest of the Low. Because of their weak Coriolis force these parcels were necessarily crossing contours and at the same time bringing warmer tropospheric air into the rear of the Low. The resulting convergence in western Oregon and California in the upper troposphere tended to lift and cool the stratosphere, and together with advection of cold air above the troposphere, overcompensated the warming below due to subsidence and advection. Thus the Low turned eastward for a time toward the region of upper level divergence over Utah and Wyoming, strengthening gradients in eastern Utah, Wyoming, and adjacent Plains States. With strengthened gradients in that area, the winds approaching from the south and west sides of the Low were not strong enough to cause continued divergence east of the Low. The area of

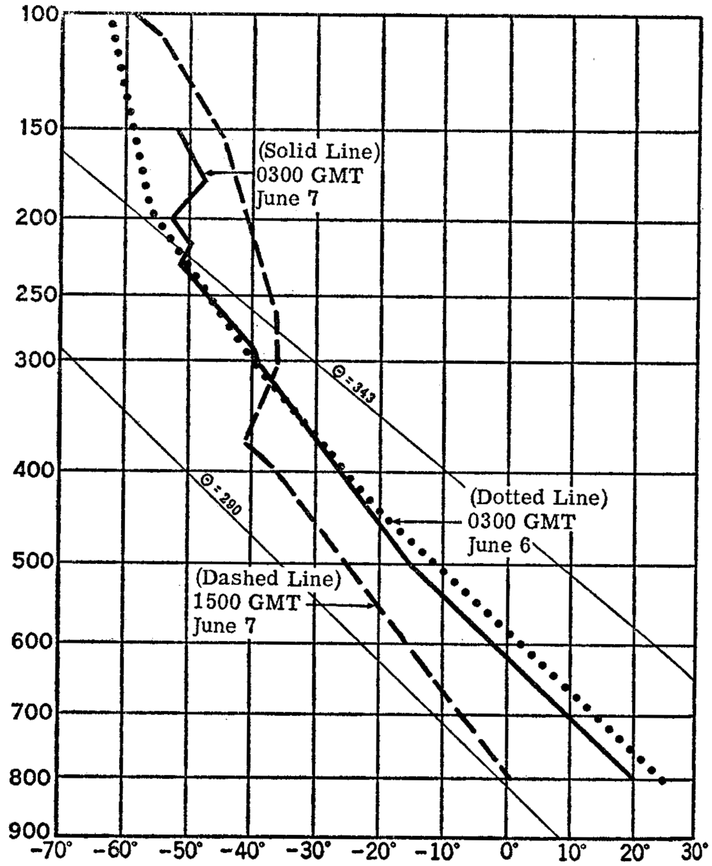

FIGURE 7.—Radiosonde observations from Ely, Nev., plotted on a pseudo-adiabatic diagram.

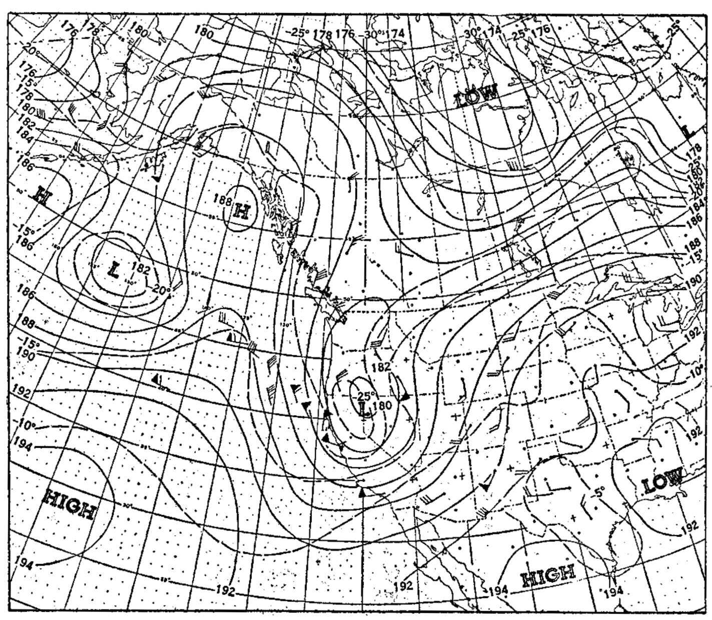

FIGURE 8.—500-mb. chart for 0300 GMT, June 7, 1950.

divergence then moved northward and northeastward causing the upper level Low to recurve to the northeast.

By 1230 GMT, June 7 snow was reported at Ely, Nev., the temperature having fallen to 31° F. A comparison of the 0300 and 1500 GMT soundings (fig. 7) at Ely on June 7 showed that the tropopause descended 10,000 feet accompanied by considerable stratospheric warming, but this was insufficient to offset the tremendous tropospheric cooling, and there was a net rise of 15 mb. pressure at the surface during the 12-hour period.

By 1530 GMT, June 7 (fig. 9) the surface Low had advanced to southwestern Wyoming. At that time the 500-mb. Low (fig. 10) was centered over northern Nevada. A trough in the 500-mb. surface extended from Kansas City, Mo., to Casper, Wyo. The resulting ridge over North Dakota and the falling contour heights over Wyoming had developed easterlies aloft over Montana. Shortly after 1500 GMT rain began changing to snow in western Montana, advection of cold air at the surface from Saskatchewan having lowered surface temperatures to the upper thirties. A comparison of the 700-mb. chart for 1500 GMT on the 7th (fig. 11) and the surface chart for that time (fig. 9) shows strong southeasterly upglide over the surface wedge of cold air moving southward over Montana. Despite the appreciable warm advection indicated toward the northwest over Montana at 700 mb., temperatures had not risen in the last 12 hours, indicating strong vertical motion. This strong vertical motion was a factor in producing substantial amounts of precipitation over Montana.

Up to this time, however, at and above 700 mb. the air had been mostly quite dry in the southwesterly flow. The high pressure ridge aloft which moved across the Southwest into Texas cut off for a time any upper level means of transport of moist air northward from the Gulf of Mexico. In figure 11 the moisture is observed for the first time as high as the 700-mb. pressure surface in the vicinity of North Platte, Nebr., and Dodge City, Kans. Immediately to the west of this area a pronounced dry tongue extended from Denver, Colo., southwestward. This dry tongue had moved northeastward from southern California in advance of the upper level Low. Thus there had been little opportunity for precipitation except in northern sections where the lift was sufficient to realize the potentialities of the shallow surface moisture.

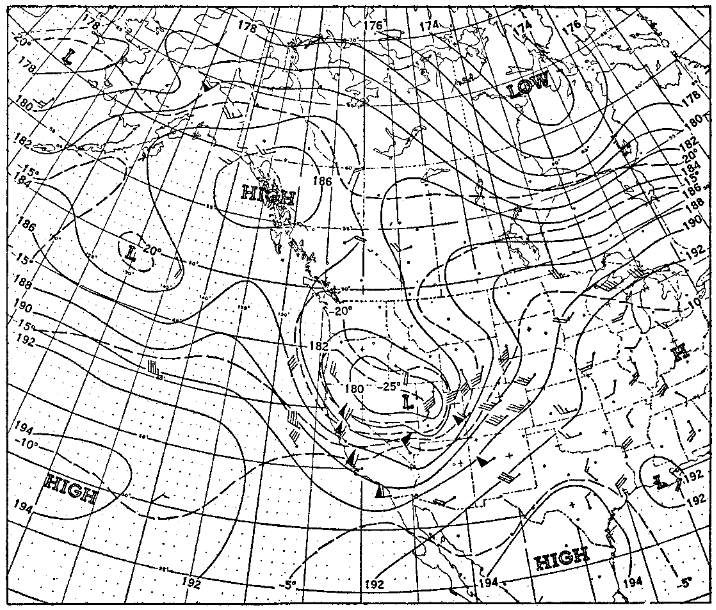

FIGURE 10.—500-mb. chart for 1500 GMT, June 7, 1950.

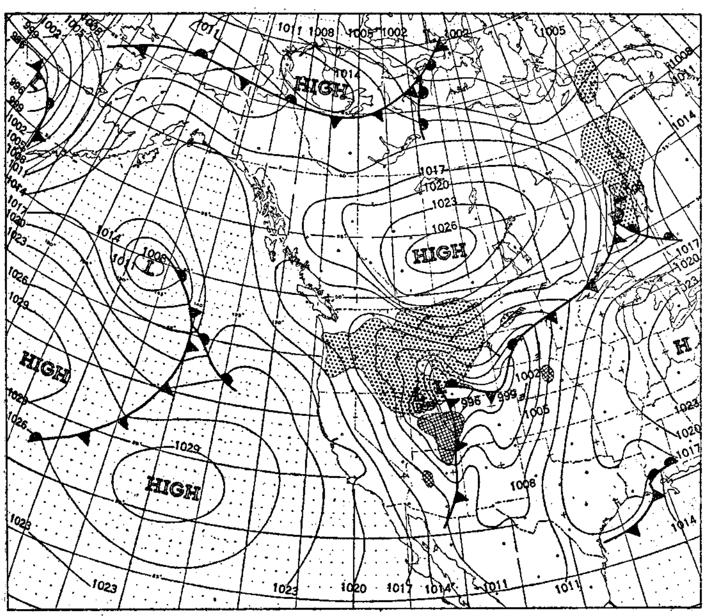

FIGURE 9.—Surface weather map for 1530 GMT, June 7, 1950. Shading indicates areas of active precipitation. Cross-hatching indicates areas of blowing dust.

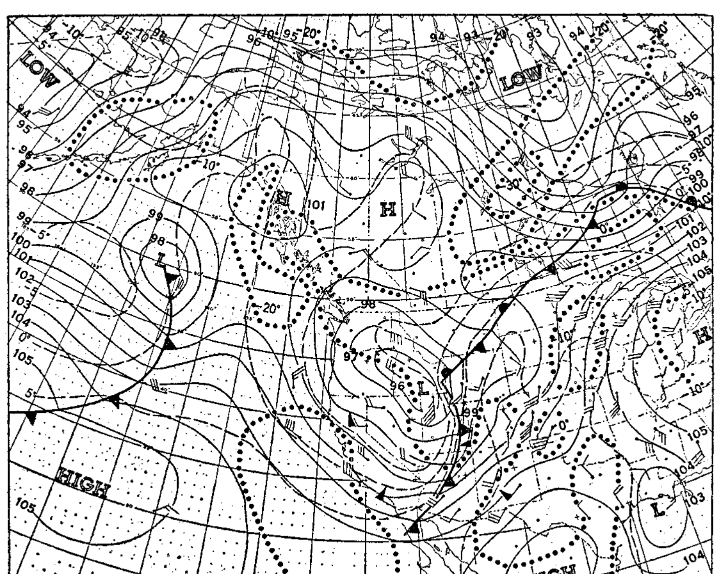

FIGURE 11.—700-mb. chart for 1500 GMT, June 7, 1950. Contours (solid lines) at 100-ft. intervals are labeled in hundreds of geopotential feet. Isotherms (dashed lines) at intervals of 5° C. Winds plotted same as figure 2. Isograms of dew point temperature (dotted lines) at intervals of 10° C.

By 1830 GMT on the 7th (3 hours after the time of fig. 9) the surface center had reached Sinclair, Wyo., having filled to 991 mb. The cold front had just passed Grand Junction, Colo., where the temperature fell 10° F. accompanied by high winds and dust.

The Low at 500 mb. at 0300 GMT on the 8th (fig. 12) had recurved to northwestern Wyoming while the surface Low (fig. 13) moved into the Great Plains near Pierre, S. Dak., with its cold front extending southward into eastern New Mexico. From Nebraska southward the weather was clear, because of eastward movement of the 700-mb. dry tongue. The moist tongue had moved eastward to eastern Nebraska and Oklahoma. Widespread dust storms accompanied the cold frontal passage in western Nebraska and eastern Colorado. This was the southernmost area to which cold air moving into the Plains reached any great depth because of the lack of any northerly component to the winds aloft.

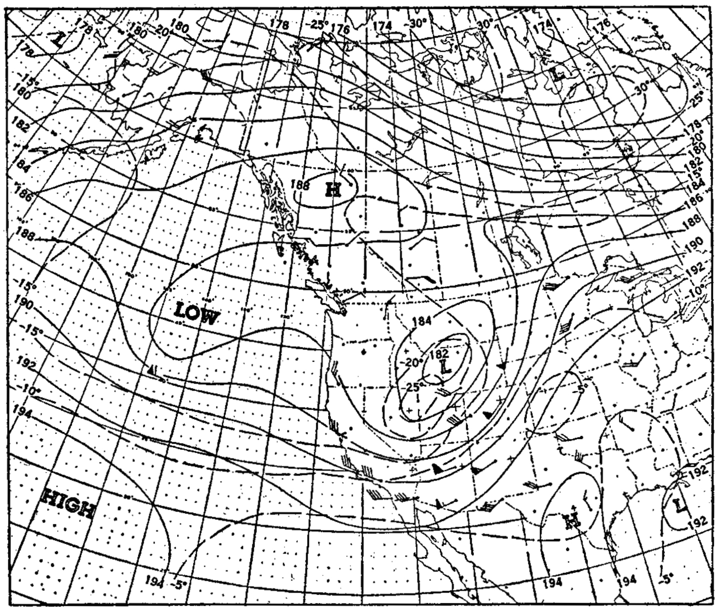

FIGURE 12.—500-mb. chart for 0300 GMT, June 8, 1950.

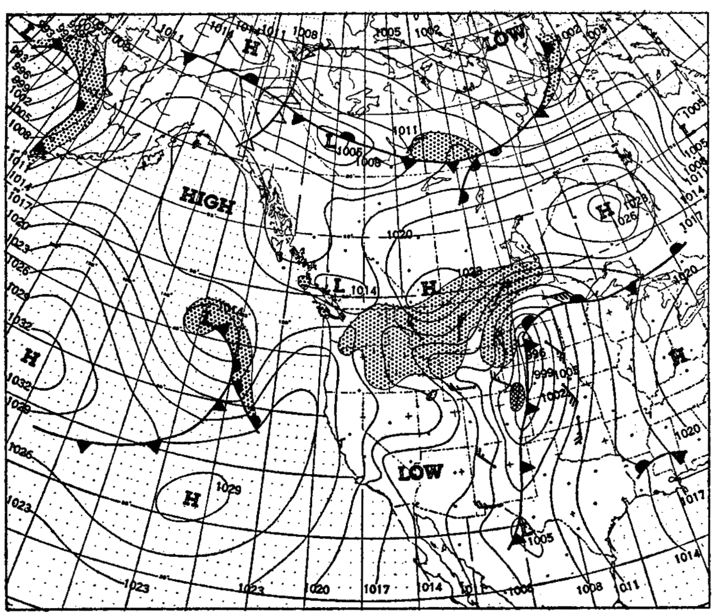

FIGURE 13.—Surface weather map for 0330 GMT, June 8, 1950. Shading indicates areas of active precipitation. Cross-hatching indicates areas of blowing dust.

At this time (fig. 13) the coldest air aloft was along the trough from northwestern Wyoming to eastern Nevada. The surface temperature at Ely, Nev., was 39° F. Weak pressure gradients and clear skies in southwestern sections of the United States indicated favorable conditions for the widespread frosts which occurred in that region by morning.

RECURVATURE AND RETROGRESSION

During the 24 hours prior to 0330 GMT of the 8th the storm moved rapidly from Utah to South Dakota along the quasi-stationary east-west front, and filled about 7 mb. Continuation of this trend would have placed the storm in 24 hours over Lake Superior. Indications in favor of this movement included the northeast to easterly winds north of the quasi-stationary front, preventing retreat of the cold air northward, and forcing the Low to move eastward. Against this trend were these indications: (1) No falls of a high level constant pressure surface were likely over Lake Superior in the immediate future, while the maximum falls were indicated over North Dakota. (2) The cold air at the surface was still moving southward over Lake Superior, precluding low level advective pressure falls in that area. On the other hand, the maximum low level warm advection was indicated chiefly over eastern North Dakota, northern Minnesota, and southern Manitoba. Thus the combination of upper level divergence and low level warm advection over eastern North Dakota suggested subsequent maximum 24-hour surface pressure falls over eastern North Dakota, spreading northward into southern Manitoba. This also indicated slow initial movement with rapid occlusion, because the quasi-stationary warm front could make only slow northward progress, chiefly by turbulent mixing between the shallow layer of cold air at its southern edge and the southerly winds in the warm air aloft.

At 0300 GMT, June 9, the Low at 500 mb. (fig. 14) had moved to northwestern North Dakota. By this time the surface storm was near Broadview, Sask. (fig. 15), having reached central North Dakota about 1230 GMT on the 8th, and then recurved to the northwest. It remained stationary near Broadview from about 0030 to 0330 GMT. At this time the surface Low was north of the upper Low. Apparently the surface system was steered to the northwest by the southeasterly winds in advance of the approaching upper system, causing low level warm advection and consequent surface pressure fall.

As the upper Low continued to the northeast in response to upper level divergence in that direction, the surface Low then recurved to the southeast under the

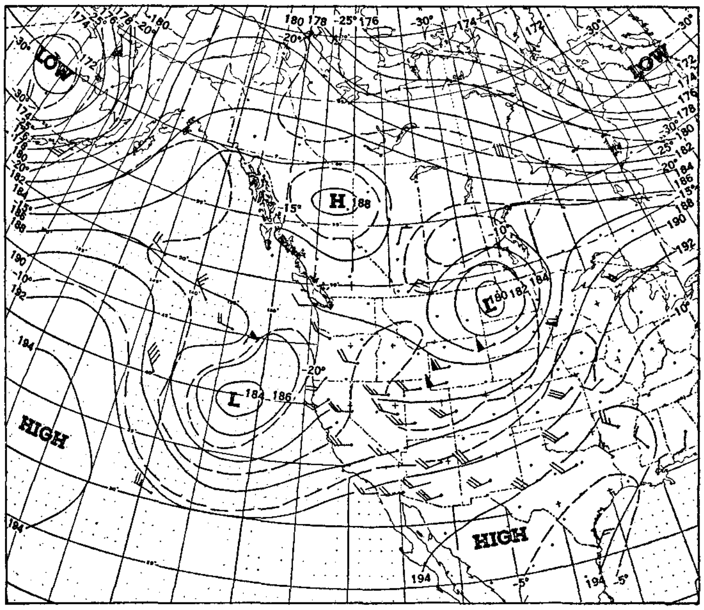

FIGURE 14.—500-mb. chart for 0300 GMT, June 9, 1950.

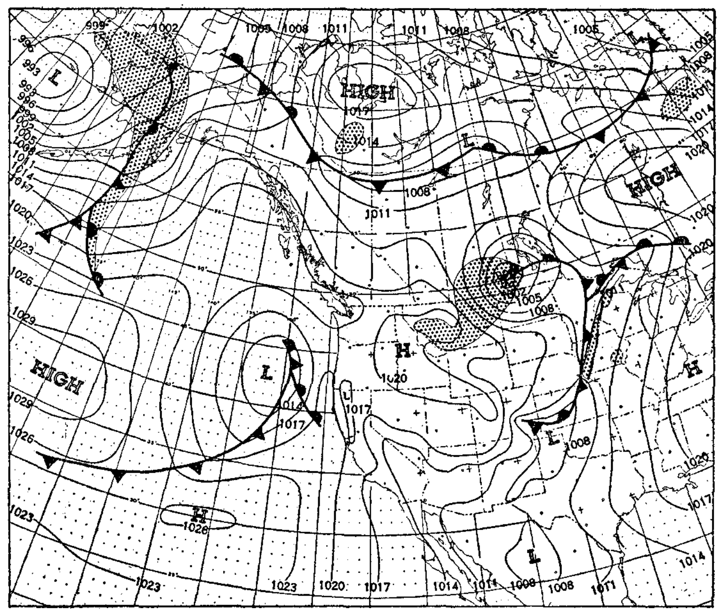

FIGURE 15.—Surface weather map for 0330 GMT, June 9, 1950. Shading indicates areas of active precipitation.

influence of the northwesterly current in the rear of the upper Low. By 0930 GMT on the 9th, the surface system had again recurved to the northeast in response to the direction of the upper level current. Six hours later, the Low was practically vertical through the entire troposphere.

Retrogression of the Low brought prolonged rains to western North Dakota, northeastern Montana, and adjacent Canadian Provinces. Some reported amounts were: Glasgow, Mont., 2.78 in.; Miles City, Mont., 1.83 in.; and Williston, N. Dak., 1.65 in.

Except for thunderstorms which broke out along a squall line through northwestern Missouri, southeastern Iowa, and northeastern Kansas on the night of the 8th, the western half of the country south of the path of the storm center remained dry during the migration of the storm from Nevada into the Canadian Provinces.

By 0330 GMT of the 10th, the Low had moved east-northeastward into southwestern Ontario, after which time it deepened rapidly due to injection of new energy into the system.

REFERENCES

1. U. S. Weather Bureau, *Weekly Weather and Crop Bulletin, National Summary,* for week ending June 13, 1950, vol. 37, No. 24.
2. H. B. Wobus and L. C. Norton, "Some Synoptic Aspects of a Change in Weather Regime during February 1950," *Monthly Weather Review,* vol. 78, No. 2, February 1950, p. 31–40.
3. J. Vederman and L. C. Norton, "The Weather Over the United States on January 26, 1950," *Monthly Weather Review,* vol. 78, No. 1, January 1950, p. 15–21.
4. J. Vederman, "Changes in Vertical Mass Distribution Over Rapidly Deepening Lows," *Bulletin of the American Meteorological Society,* vol. 30, No. 9, Nov. 1949, p. 303–309.

U. S. GOVERNMENT PRINTING OFFICE: 1950